Characterization of the water quality and biota of a stormwater wetland one year after its creation

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Abstract

Long-term monitoring of created wetlands provides valuable information about their development and functioning. Data gathered in the early stages of a created wetland's development provide a benchmark for future assessment. The objective of this study was to examine the water quality and plant and animal communities of a 1-year old stormwater wetland that was created to intercept and detain roof runoff at the Olentangy River Wetland Research Park, Columbus, OH, USA. Water quality parameters were compared to those of an adjacent one-year-old wetland fed by river water. A well-developed wetland plant community was documented, as well as numerous amphibians and a variety of benthic invertebrates. The pH of the wetland was neutral to alkaline (7.95 ± .18), although the pH of roof runoff was very acidic (3.92 ± .71). Conductivity and redox potential were significantly lower than those of the river-fed wetland. Concentrations of NO_3^- and SRP were very low (avg. 0.746 ± 0.00 and 0.046 ± .03 respectively), although values for NO_3^- may have affected by samples remaining unacidified until just prior to analysis.

Introduction

Urban and suburban development results in the replacement or covering of porous, vegetated areas with impervious surfaces such as asphalt that capture and redirect precipitation. Water displaced in this manner is known as urban runoff; this runoff contributes to the pollution of streams and rivers, increased magnitude of flooding, overloading of sewers and reduced groundwater recharge (Schueler, 2000a). Urban runoff is second only to agriculture in quantity of non-point source pollution produced (Reinelt and Horner, 1995). Where impervious surfaces replace vegetation, percolation of rainwater into the ground is inhibited, and precipitation is channeled quickly to low areas of the landscape occupied by waterbodies or sewers (Ellis, 1989). The type and magnitude of pollutants absorbed by runoff depends upon the surface(s) over which urban runoff travels (Schueler, 2000a).

Wetlands perform a variety of functions in the landscape, including the detention of floodwaters and runoff, the adsorption, chemical transformation or removal of nutrients and pollutants, and they provide habitat for a diverse array of species (Mitsch and Gosselink, 2000). Human domination of the Earth's landscape has been accompanied by the destruction of approximately half of the world's wetlands (Finlayson and van der Valk, 1995). As a consequence, the valuable functions performed by wetlands have been compromised on local, watershed and landscape scales (Bedford, 1999). Problems associated with urban runoff and the loss of wetland area can be addressed simultaneously by creating wetlands to capture and detain runoff. In addition, stormwater basins can provide recreational and aesthetic benefits for urban communities (Ferguson, 1991). Wetlands created for stormwater attenuation are referred to as stormwater ponds, stormwater control basins, stormwater wetlands, or as a subcategory of treatment wetlands; such wetlands are in use throughout the U.S. and other countries (Carleton et al., 2001; Ellis, 1989).

The effectiveness of stormwater wetlands in removing pollutants is dependent upon the season in northern climates (Oberts and Osgood, 1991), the residence time of water in the wetland, and the presence of vegetation, which can promote sedimentation and nutrient uptake (Brown, 1985). There is high variation in pollutant-removal effectiveness among stormwater wetlands due to physical and structural differences between systems (Schueler, 2000b). Data describing the long-term performance of stormwater wetlands are scant, suggesting that long-term assessment of these systems is an important area of research in the fields of wetland science and ecological engineering (Carleton et al., 2001).

A stormwater detention wetland was constructed at the Olentangy River Wetland Research Park, on the campus of the Ohio State University, Columbus, OH, in October 2002. This wetland occupies 0.13 hectares and a volume of 575 m^3 (Fig.1), and was designed to receive runoff from the roof of a new office building constructed at the same site. Precipitation is channeled into four outlets that discharge from the roof into gravel depressions on the ground, and enters the wetland from below ground. The objective of this study was to evaluate the water chemistry, plant, amphibian, reptile and benthic invertebrate communities of this stormwater wetland system one year after its creation (October 2003). Water quality parameters were sampled between, during and after storm events in order to compare chemistry of precipitation with chemistry of water in the wetland, and potential storm-induced changes in the wetland's water quality. In addition, a comparison was made of water quality parameters between the stormwater wetland

and an adjacent wetland of similar area (0.166 hectares), volume (964 m^3) and age (1 year). This wetland, called the 'bioreserve pond', receives water from the Olentangy River after it passes through on-site wetlands, from ground water and from overland flow around its perimeter. It is expected that data obtained from this study will serve as a baseline reference for monitoring of the stormwater wetland over the long term.

Methods

Plant community

Herbaceous and woody plant species were surveyed on 18 October, 2003. A visual survey was conducted around the perimeter of the stormwater wetland, and all identifiable species were recorded. Species dominating percent cover at the canopy, sub-canopy and water surface within two vegetation zones (edge of open water to edge of thick vegetation and edge of thick vegetation to upland) were recorded. Percent cover of algae was estimated on 24 Oct. for two depth zones: <30 cm, and >30 cm. Algae abundance was determined by walking the perimeter of each side of the pond, and estimating percent cover of the water surface, and percent cover below the surface of the water.

Amphibians and reptiles

Nine minnow traps were deployed on 8 October at 10:30 a.m. and recovered at 4:30 p.m. the same evening. Traps were again deployed on 10 Oct. at 5 p.m. and recovered at 11:30 a.m. on 11 October. Traps were placed at 10-m intervals around the edges of the wetland and positioned so that the entry was submerged but the upper part of the trap remained exposed to air to prevent frogs and snakes from drowning. At 6 p.m. on 11 Oct., one trap was submerged in a deep- water area by the outflow of the pond and recovered at 9:30 a.m. on 12 October. On 8 Oct., a 1-m x 1.5-m board was placed on the ground over vegetation where standing water was absent on each side of the wetland. Boards were lifted twice per week to check for amphibians and reptiles. Visual surveys of amphibians were made during the trapping period and observations were recorded.

Benthic invertebrates

Hestor-Dendy plates were deployed on 14 Oct. at three locations in the stormwater wetland: one at 28-cm depth on the NW end of the wetland, one at 46-cm depth in the middle of the wetland, and one at 64-cm depth by the outflow weir. Plate dimensions were 8cm x 8cm x 8cm, and fishing bobbers attached to a nylon line were used to mark their location for later recovery. Plates were allowed to settle onto the bottom of the wetland. Plates were retrieved on 29 Oct. by carefully lifting them so that their contents would not be disturbed. They were then placed in a plastic bag for transport into the lab. Plates were individually washed over a bucket and invertebrates were removed and placed in jars filled with 70% ethyl alcohol until identification. Specimens were identified to family using Lehmkuhl (1979) and Voshell (2002), and numbers of individuals of each family were recorded.

Water chemistry

Temperature, specific conductivity, pH, oxidation-reduction potential, and dissolved oxygen were determined twice per week in the morning and evening with a YSI 610-D, 600 XL water quality monitor. Measurements were taken at the inflow and outflow areas of the stormwater wetland and at open and closed ends of the bioreserve pond. The open end of the bioreserve pond receives water discharged from on-site marshes through a swale during flood events and the closed end receives overflow from the stormwater wetland weir when the water level reaches 0.91 cm.

Grab samples were taken weekly at the inflow and outflow of the stormwater wetland, from Oct. 8-27, 2003. Roof runoff was captured from two storm events, on 10 and 26 Oct. 2003. This runoff was analyzed with the YSI, and

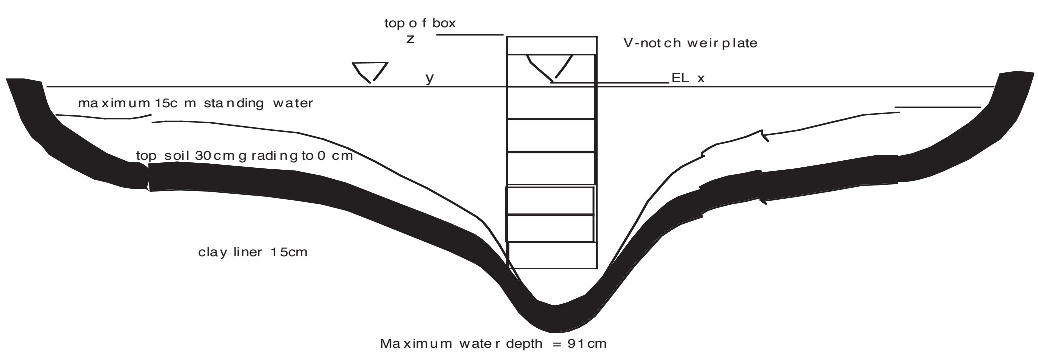

Figure 1. Cross-section of design of stormwater wetland basin. Basin is 3-sided, having north, south and west-facing edges.

the sample on 26 October was of sufficient volume to test for nitrate (NO_3^-) and soluble reactive phosphorus (SRP). Wetland water samples were taken during and after storm events when possible. All samples were stored at 4^0 C until treatment and analysis. Treatment consisted of acidification of 100-ml samples with 0.5 ml H_2SO_4 for analysis of NO_3^-, and vacuum filtration of 100-ml samples through 0.45mm filter paper for analysis of SRP. Samples were analyzed with a Lachat QuikChem FIA+8000 with an ASX-500 Autosampler.

Results and Discussion

Plant community

Thirteen herbaceous and woody plant species were observed around the stormwater wetland including a minimum of five species that were planted in April 2002 and a maximum of eight that were not (Table 1). Because *Carex* were not identified to species, it could not be determined whether these species were planted. Plant sampling took place after some species had completed flowering or had senesced. Although certain species were clearly dominant at this time (Table 2) species that had completed their life cycles earlier in the season were not accounted for.

Of the 13 herbaceous and woody species observed, six were OBL wetland species, two were FACW+, one was FAC, and one FAC- (Table 1). The wetland status of *Carex* spp. could not be determined without species identification. Species dominating percent cover were FACW+ and OBL species indicating strong development of a wetland plant community after one growing season. At least three of the five dominant emergent plant species were introduced by seed in spring 2003. *Eleocharis* (OBL) and algae species were not planted but were abundant in the stormwater wetland; five additional species were observed that were not planted including *Ludwigia palustris* (L.) Elliott and *Lycopus* sp., both OBL wetland macrophytes. Waterfowl including mallards (*Anas platyrhynchos*) and wood ducks (*Aix sponsa*) were observed in the wetland and it is possible that seeds were transported to the wetland on the bodies or in the excrement of ducks. Although direct observations of muskrats (*Ondatra zibethicus*) were not made, evidence of muskrat activity included *Sparganium* plants eaten during the course of the study and burrows made in the northeast edge of the wetland. Muskrats could carry seeds or other propagules in their fur and excrement as well.

Algae were abundant in the wetland the day sampling was carried out. Up to 35% of the water surface was covered with algae and up to 70% of the below-surface area was covered with algae (Table 3). Because algae were quantified on only one day these measurements do not reflect changes in the quantity of aquatic plants over the growing season. In addition, percent cover of algae on the surface of the water can vary on a daily basis according to the action of wind.

Table 1. Herbaceous and woody plant species observed in the stormwater wetland, Oct. 2003

Wetland aspect	Depth interval	Species observed; * = planted April 2002; wetland indicator status from Chadde, 1998
North	Edge of open water to edge of dense vegetation	Prairie cordgrass (*Spartina pectinata* Link)* FACW+; Nodding bur-marigold (*Bidens cernua* L.)* OBL; Soft rush (*Juncus effusus* L.)* OBL; Giant smartweed (*Polygonum pensylvanicum* L.)* FACW+; *Eleocharis* sp. OBL
	Edge of dense vegetation to upland	*S. pectinata*, other grass spp., *Carex* spp., *B. cernua*, Goldenrod (*Solidago* sp.), *Eleocharis* sp.
South	Edge of open water to edge of dense vegetation	*B. cernua, S. pectinata, J. effusus, P. pensylvanicum, Eleocharis*, Marsh purslane (*Ludwigia palustris* (L.) Elliott) OBL
	Edge of dense vegetation to upland	*Carex* spp., *S. pectinata, B. cernua, P. pensylvanicum, Eleocharis* sp., Calico aster (*Aster lateriflorus* (L.) Britton) FACW-, Water horehound (*Lycopus* sp.) OBL
West	Edge of open water to edge of dense vegetation	*Eleocharis* sp., *B. cernua, P. pensylvanicum, S. pectinata, J. effusus*, Bur-reed (Sparganium sp.)* OBL
	Edge of dense vegetation to upland	*Carex* sp., *Eleocharis* sp., *B. cernua, P. pensylvanicum, Lycopus* sp., Red maple seedlings (*Acer rubrum* L.) FAC

Table 2. Plant species dominating percent cover in the stormwater wetland at various canopy levels

Canopy zone	Dominant species (order of dominance); * = planted April 2002; wetland indicator status from Chadde, 1998
Canopy	*S. pectinata** FACW+
Subcanopy	*Carex* sp. (1), *B. cernua** (2) OBL, *P. pensylvanicum** (2) FACW+
Water surface at edge of emergent vegetation	*Eleocharis* sp. OBL

Table 3. Percent cover of algae on and below surface of stormwater wetland, Oct. 24, 2003

Wetland aspect	Depth interval	Percent coverage of water surface	Percent cover below water surface
North	0-30 cm	10%	30%
	>30 cm	35%	35%
South	0-30 cm	30%	70%
	>30 cm	5%	10%
West	0-30 cm	15%	55%
	>30 cm	10%	50%

Table 4. Amphibians and reptiles captured and observed at the stormwater wetland Oct. 8-12, 2003

Date of trap recovery or dipnetting	Species captured (number of individuals)	Species observed but not captured
Oct. 8, 2003 (traps)	Ø	*R. catesbeiana*
Oct. 10, 2003 (dipnet)	*Rana catesbeiana* (1)	*R. catesbeiana* tadpoles (>12) *Thamnophis sirtalis* (1)
Oct. 11, 2003 (traps)	*R. utricularia* (2) *R. catesbeiana* (1)	*R. utricularia* (>5)
Oct. 13, 2003 (trap)	*R. catesbeiana* tadpoles (9)	Ø

However, this measure provides a point of comparison for future studies.

Amphibians and reptiles

Two frog species were observed, the Southern leopard frog (*Rana utricularia*) and bullfrog (*Rana catesbeiana*) (Table 4). Only adult *R. utricularia* were observed, while larval, juvenile and adult forms of *R. catesbeiana* were found in and around the wetland. The only reptile observed during the study period was a garter snake (*Thamnophis sirtalis*). No amphibians or reptiles were found under the boards. However, mice and rats occupied each of the below-board habitats within 24 hours of board deployment. It is possible that these mammals were a deterrent to amphibian use of habitat beneath the boards. A partially eaten leopard frog was found with rats under the board on the south side of the wetland on 30 October, at which point boards were removed from the study area.

Benthic invertebrates

Five families of benthic invertebrates colonized the Hestor-Dendy plates: Coenagrionidae (damsel fly larvae), Physidae (pond snails), Haliplidae (aquatic beetles) and Aeshnidae (darner larvae). A total of 12 invertebrates were recovered from the plates, the majority of which were attached to plates at 28 and 46-cm depth (Table 5). A study of benthic invertebrates at the ORWRP in two six-month-old riparian marshes fed by water from the Olentangy River provides a contrast to results presented here (Nairn et al., 1995). Nairn et al (1995) deployed 11 plates for 21 days in the marshes and recovered a total of 772 individual invertebrates representing four orders. This suggests that river-fed wetlands receive a substantial supply of these animals from their water source, in contrast to the stormwater wetland that receives only precipitation and runoff.

Water chemistry

Table 5. Benthic invertebrates found on Hestor-Dendy plates in stormwater wetland, Oct. 2003

Plate # (depth)	Families (# individuals)
1 (28 cm)	*Coenagrionidae* (3)
	Physidae (3)
2 (46 cm)	*Haliplidae* (1)
	Aeshnidae (3)
3 (64 cm)	*Physidae* (2)

No significant difference ($\alpha = 0.05$) was found between the inflow and outflow of the stormwater pond for any of the water chemistry parameters over the sampling period (Table 6). The average temperature, dissolved oxygen content, pH, specific conductivity and redox potential in the stormwater wetland and the bioreserve pond are illustrated in figures 2-4. T-tests $\alpha = 0.05$) indicated no significant difference in average temperature, dissolved oxygen or pH between the two systems (Figure 2). Significant differences were found in specific conductivity (Figure 2) and redox potential (Figure 3) between the stormwater wetland and bioreserve pond, with both parameters being lower in the stormwater wetland. Specific conductivity is an indication of the concentration of dissolved ions in water (Potapova and Charles, 2003). The flow path of water entering the stormwater wetland is short in comparison to that of the bioreserve pond. Stormwater probably becomes enriched with Ca^{2+} as it travels over limestone gravel into the wetland, which could account for some of the dissolved ions in addition to helping create the circumneutral pH of this system. Water from the Olentangy River enters the bioreserve pond after passing through wetlands at the ORWRP. In addition, the bioreserve pond receives groundwater and overland flow. As a result this water is likely to be high in organic matter and dissolved ions relative to water in the stormwater wetland.

Redox potential is an indication of a solution's tendency to accept or donate electrons (Stumm and Morgan, 1981). When free dissolved oxygen is depleted from a solution, organic matter is oxidized via the reduction of a series of terminal electron acceptors associated with decreasing redox potential (Mitsch and Gosselink, 2000). The maximum variation in redox potential between the stormwater wetland and bioreserve pond, including standard error, was 232–281 mV (Figure 4). After depletion of O_2 from an aqueous solution, NO_3^- is generally the first electron acceptor to be reduced, a reaction that occurs at a redox potential of approximately 225-250 mV (Mitsch and Gosselink, 2000). Denitrification could occur in the soils of the stormwater wetland, given the average redox potential of 243 mV in the overlying water. Water level was never sufficiently high to result in discharge from the overflow weir during the study period, so water retention time in the wetland was affected mainly by evapotranspiration or percolation to groundwater. The resulting lengthy retention time could facilitate denitrification. All water samples analyzed for NO_3^- concentration produced virtually the same result (0.745 - 0.746 mg N/L). It is probable that changes in concentration of NO_3^- occurred prior to acidification of the samples, or that errors were made in the operation of the Lachat Autoanalyzer. Although water samples were stored at 4^0C, they were not acidified until analysis was performed. The concentration of soluble reactive phosphorus (SRP) also varied little among water samples with concentrations ranging from 0.01 to 0.05 mg P/L. A t-test revealed no significant difference in concentration of SRP in water samples taken between rain events and samples taken during/after rain events.

Roof runoff was much lower in pH, and higher in redox potential, than water in the stormwater wetland (Table 6). The pH reached its lowest daily averages, and redox potential its highest daily averages, after rain events on 14 and 26 October (Figure 5). However, pH reached its highest and redox potential reached its lowest daily average following a storm event on 10 October (Figure 5). It is apparent that significant buffering occurs in the wetland and possibly before stormwater reaches the wetland. The presence of a large quantity of algae and emergent macrophytes in the stormwater wetland is likely to contribute to the buffering by photosynthetic removal of the weak acid bicarbonate HCO_3^- (Cavalcanti et al., 2001). Once captured by the wetland the redox potential of water falls as oxygen is consumed by respiration of organic matter in the system.

Conclusions

One year after its creation the stormwater wetland at the Olentangy River Wetland Research Park effectively detains and neutralizes roof runoff. Despite numerous storm events the wetland did not reach the overflow point during this study. The stormwater wetland also provides habitat

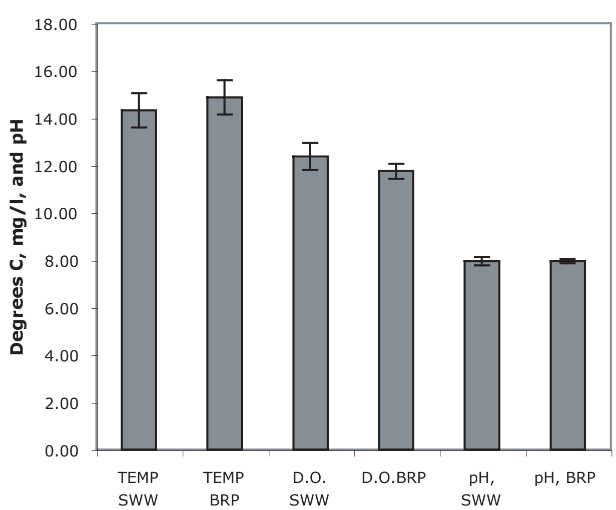

Figure 2. Average temperature (°C), dissolved oxygen (mg/L) and pH of stormwater wetland (SWW) and bioreserve pond (BRP), Oct. 2003. Bars represent standard error.

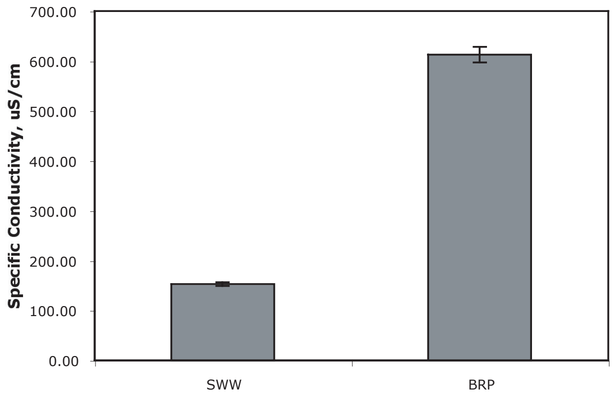

Figure 3. Comparison of specific conductivity in the stormwater (SWW) and the bioreserve pond (BRP) Oct. 2003. Bars represent standard error.

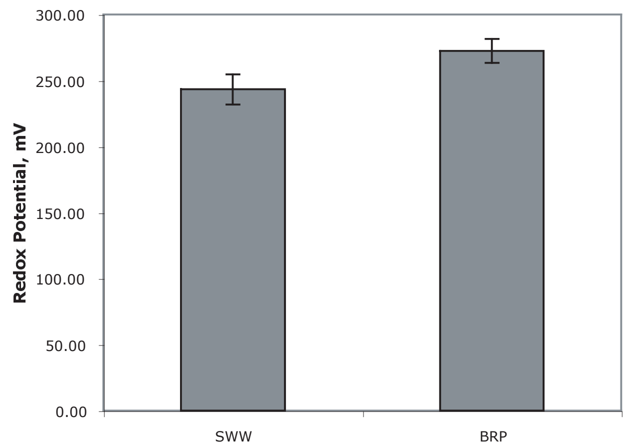

Figure 4. Comparison of redox potential of stormwater wetland (SWW) and bioreserve pond (BRP), Oct. 2003. Bars represent standard error.

Table 6. Averages of water quality parameters in roof runoff and stormwater pond, Oct. 2003

Water Source (# replicates)	Average temperature, ∝C (standard error)	Average pH (standard error)	Average Redox (standard error)	Average Conductivity, mV (standard error)
Roof Runoff (2)	10.18 (0.570)	3.92 (0.71)	467 (22)	98 (58)
Stormwater Wetland (≤ 31)	14.32 (0.723)	7.95 (0.18)	243 (11)	153 (4)

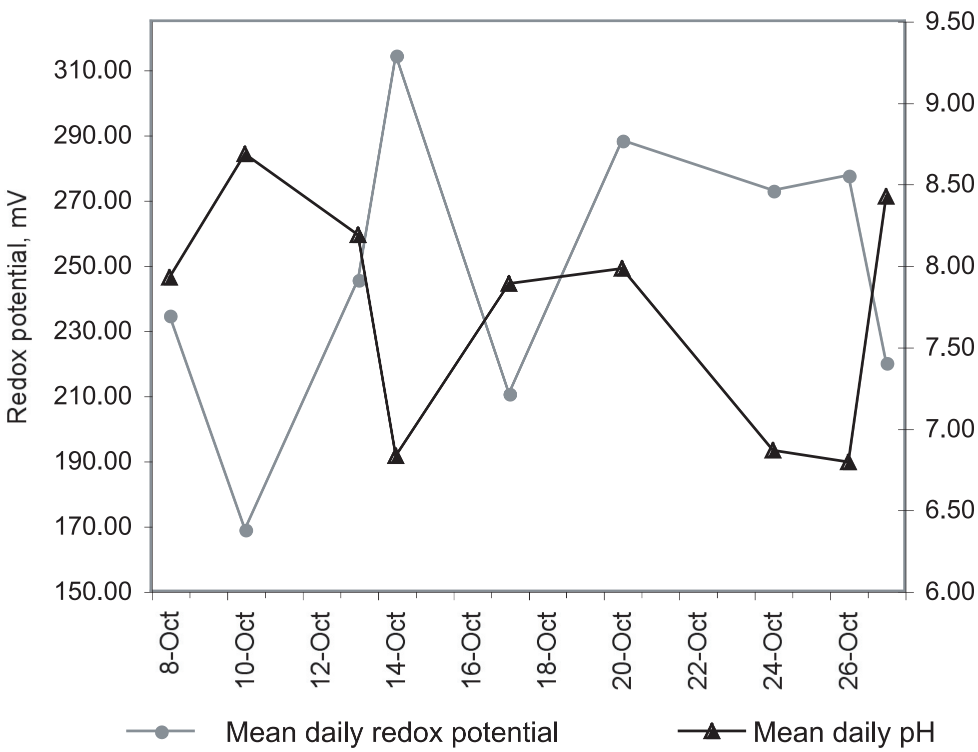

Figure 5. Mean daily values for redox potential and pH in the stormwater wetland.

for a variety of species of wetland plants, invertebrates, mammals, and amphibians. Future studies examining biota throughout the year, and especially during the growing season, would provide a more complete census. In addition, studies that captured storm events resulting in outflow from the stormwater wetland, in addition to testing roof runoff and water at the inflow area, would provide a more comprehensive understanding of the effects the wetland has on water quality

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